

MEMORANDUM

To: Tina Laidlaw, USEPA, Region 8

Date: October 21, 2016

Cc: Mario Sengco, USEPA
Gary Russo, USEPA

Subject: State of Montana wastewater
system nutrient reduction cost
estimates

From: Victor D'Amato, PE
Steven Geil

1.0 INTRODUCTION

Tetra Tech was tasked with providing cost estimates for major and minor NPDES wastewater treatment plants (WWTPs) in Montana to move from their current levels of effluent total nitrogen (TN) and total phosphorus (TP) performance to Limits of Technology (LOT) levels. Major publicly owned treatment works (POTWs) are those that have a design flow of one million gallons per day (MGD) or more, are required to have a pretreatment program, or have the potential to cause significant water quality impacts. Non-municipal facilities (non-POTWs or industrial facilities) are those scoring 80 points or more using the EPA NPDES Permit Rating Work Sheet. All facilities not considered major facilities are considered minors. LOT was defined as indicated below.

- LOT_{7.0TN}: 7.0 mg/l TN (optimization of existing activated sludge process to promote nitrification/denitrification)
- LOT_{3.0TN}: 3.0 mg/l TN (biological nitrogen removal: nitrification/denitrification via anoxic/oxic zone or cycle retrofits, addition of a denitrification filter, or optimization for plants approaching LOT)
- LOT_{0.5TP}: 0.5 mg/l TP (enhanced biological phosphorus removal, EBPR: anaerobic selector technology with tertiary filtration)
- LOT_{0.1TP}: 0.1 mg/l TP (chemical precipitation with tertiary filtration)

- LOT_{0.05TP}: 0.05 mg/l TP (high dose chemical precipitation with advanced solids removal process¹)

For the purposes of this planning level evaluation, we defined two LOTs for TN. An effluent TN of 7 mg/l was assumed to be achievable by activated sludge WWTPs following efforts to optimize their existing treatment processes regardless of whether the WWTP was originally designed for biological nitrogen removal. 7 mg/l was selected based on the median TN achieved after optimization of 22 WWTPs in the US (USEPA 2015a, Water Planet 2016), including 12 from Montana (median effluent TN for all optimized plants was 6.1 mg/l). A second, higher level LOT of 3 mg/l TN was defined based on widely-accepted LOT for systems specifically designed for biological nitrogen removal. The difference between LOT_{7.0TN} and LOT_{3.0TN} is that the former has been shown to be achievable at most WWTPs by simply optimizing existing activated sludge systems largely irrespective of their original design, with minimal capital costs. Optimization typically involves improved control of existing aeration systems using DO, ORP and/or other meters integrated with existing or new aerator controls. In some cases, the installation of mixers is required to allow these plants to achieve low effluent TN via optimization. LOT_{3.0TN} generally must be met by investing in additional treatment facilities (e.g., reactors, mixers, recycle lines), although some plants with current effluent concentrations approaching 3.0 mg/l may be able to optimize to meet the LOT. Both approaches leverage biological nitrogen removal - sequential nitrification and denitrification - which can be achieved using unaerated (anoxic) and aerated (oxic) zones or cycles. The installation of denitrification filters after activated sludge treatment can also be used for meeting the LOT_{3.0TN} where this approach is more feasible.

For phosphorus removal, we defined three LOTs, since each increment of TP reduction typically requires significant differences in technology and associated costs. LOT_{0.5TP} generally assumes enhanced biological phosphorus removal (EBPR) with tertiary filtration (e.g., moving bed filters, media filters, cloth/screen filters). LOT_{0.1TP} includes chemical precipitation and tertiary filtration. This technology is often capable of reducing TP concentrations to 0.05 mg/l or even less, but not reliably. To meet a TP of 0.05 mg/l consistently (i.e., LOT_{0.05TP}), tertiary solids removal would need to use more advanced solids removal processes. The practical significance of this distinction is that if water quality standards demand that effluent TP limits be stated in terms of annual mass loading for example, LOT_{0.1TP} may be sufficient. If, on the other hand, effluent TP must be below 0.05 mg/l all the time (or frequently, e.g., monthly average), then LOT_{0.05TP} may be more appropriate. It appears that Montana's major NPDES permits are currently written to include annual (or seasonal) mass load limits for TP. This suggests that LOT_{0.1TP} may be sufficient. However, costs for meeting both LOTs are provided in this analysis for comparative purposes.

2.0 METHODS

Tetra Tech based this planning-level analyses on existing published information on nutrient removal costs. Primary sources of cost data are cited in Section 4, References.

¹ Advanced solids removal process can include certain membrane filters, reactive media filters, continuous backwash media filters, microfilters, cloth filters, ballasted and other enhanced settling processes and combinations of these technologies. For the purposes of this evaluation, costs were assumed to be comparable.

It is important to note that the accuracy of the estimated costs reported herein is estimated to be in the range of -50 percent to +100 percent, at best, consistent with a Class 5 Planning Estimate as defined by the Association for the Advancement of Cost Engineering.

The evaluation assumes that flows for the WWTPs will remain constant; we have made no explicit consideration for growth, as this would add another level of uncertainty into the analysis and make it even more critical to collect and consider additional design information prior to costing.

EXISTING FACILITY CHARACTERIZATION

Existing facilities were characterized using a combination of the following information:

1. Process descriptions in permits
2. Information provided by USEPA and Montana DEQ
3. Information on systems found on the Web
4. Google Earth aerial photography of the WWTP
5. Effluent data

Of the 9 major and 7 minor NPDES WWTPs evaluated, all use variants of the activated sludge process, with the exception of the City of Whitefish which currently uses an aerated lagoon (but is upgrading to a biological nutrient removal plant) and Manhattan which uses a fixed film system designed for biological nitrogen removal. Additionally, the Butte Highlands Mine uses a membrane filtration process. Effluent from Butte Highlands appears to be well below the specified LOTs, so the facility is not considered in the cost analysis. Other mine facility WWTPs were not considered in this evaluation at the direction of USEPA.

Of the activated sludge plants, several were specified to be biological nutrient removal (BNR) systems. Additionally, Montana DEQ provided additional details about the capabilities and future plans of several of the plants. However, in general, design/configuration details are largely unknown for most of the systems, which limits the overall confidence we have in estimating the modifications required to meet the different LOTs and associated costs. Some of the other activated sludge systems that were not explicitly specified as BNR systems appear to be meeting BNR system effluent quality for TN, TP, or both. Where this is the case, we made assumptions as to the “starting point” for the system (the data used to estimate costs in many cases depends both on the LOT of the modified systems as well as the characteristics of existing systems which informs the types of modification required). The primary factors for estimating the existing system type and performance capabilities included:

1. Narrative descriptions of existing system.
2. Actual current treatment performance (based on reported effluent results). For the major WWTPs, we also considered the current permit limits (we did not have access to nutrient load limits for the minor WWTPs). We used the major WWTPs’ actual average flows and permitted TN and/or TP effluent mass limitations to calculate equivalent effluent concentrations required to meet current nutrient load limits and compared these with actual, measured effluent concentrations. Where the permitted load-based concentration was close to the measured concentration, we assumed that the plant was consciously trying to optimize their process to lower effluent nutrient concentrations in order to meet their permit limits now and to prepare for higher future flows. Where the permit-based concentrations were significantly higher than the measured concentrations, we assumed that there wasn’t currently a strong driver to optimize nutrient reduction and that it was likely that the plant could achieve significantly lower concentrations if necessary.

It should be noted that we conducted an internet search to try to collect additional information about the 9 major WWTPs. Although most local governments had a page on their website about “wastewater treatment”, in most cases no additional useful details were found. However, we did locate a facility plan for the City of Hamilton from 2006, and a detailed case study (from 2015) for the City of Bozeman’s nutrient reduction efforts from another project that Tetra Tech is working on for EPA-OWOW. Replacement costs for the Whitefish lagoon (presumably to replace with a BNR system) were also located. Nevertheless, our evaluation was data constrained for all of the facilities. Master planning and design documents with associated detailed facility layouts and flow diagrams would be useful in making more confident judgements about the work that might be needed to meet LOT effluent quality characteristics for the facilities (although it should be noted that this exercise would require a much higher level of engineering analysis as well).

Although we tried to treat all WWTPs consistently, we considered the characteristics of each WWTP individually and have documented our assumptions about existing facilities in Table 1 (major WWTPs) and Table 2 (minor WWTPs).

LIMIT OF TECHNOLOGY SELECTION

The selection of appropriate LOTs for modifications were based on:

1. Actual current treatment performance. If a plant was already meeting an LOT or should meet an LOT based on their upgrade plans, no estimate was done for that LOT.
2. Reasonable potential analysis (RPA) and water quality-based effluent limits (WQBELs) results from previous efforts for several WWTPs. If an LOT concentration was lower than the RPA/WQBEL concentration, then no estimate was done for that LOT.

As indicated in Table 3 (for major WWTPs) and Table 4 (for minor WWTPs), we assumed that the activated sludge plants were either meeting LOT_{7.0TN} or could be optimized to do so. Optimization, in this context, includes activities such as retrofitting with better aeration equipment, mixers to promote anoxic treatment, and various control systems. However, it is important to note that optimization costs could vary widely and are particularly facility-specific and difficult to generalize². These plants were assumed to be able to meet LOT_{3.0TN} via applicable retrofits, as specified in the tables. For plants performing close to the LOT_{3.0TN} (e.g., TN = 4.5 mg/l or less), we assumed that they were capable of meeting LOT_{3.0TN} through existing facility optimization. We used different unit costs for optimization for the two different LOTs as well as for the minor versus major WWTPs, based on the data in the two references used to estimate costs for optimization (EPA 2015a, Water Planet 2016).

For TP reduction options, we generally did not differentiate between plants currently achieving different levels of effluent TP in terms of how they would be able to achieve the different LOTs. For example, a plant with a current effluent TP of 0.5 mg/l was treated the same as one with a current effluent TP of 1.5 mg/l to get down to different LOTs, even though the 1.5 mg/l plant could, for example, require more chemical addition to achieve the same effluent limits as the 0.5 mg/l plant. The data we used generally did not discriminate between different starting TP levels, so making a correction would have required modifying the source data which we wanted to avoid so as to maintain the integrity of the source data.

² In many cases, TN reduction optimization results in overall savings in recurring (O&M) costs due to reduced energy usage.

Additionally, our opinion was that such a refinement would be lost in the noise of the data and the errors inherent to the number of assumptions being made. One exception to this was for plants using chemical P removal and achieving close to, but not quite 0.10 mg/l TP. In these cases, we assumed that additional alum dosing would lower TP further and used unit costs for alum treatment to estimate O&M costs.

COST ESTIMATION

As previously indicated, a list of references is provided in Section 4. References used for cost estimation were carefully selected and are consistent with references used for previous similar work by Tetra Tech and others. In general, we sought references that provided costs that could be generalized for other, similar facilities. In most cases, the references were intended to address planning level costs for retrofits of facilities over broad geographic areas (e.g., statewide assessments), which is consistent with the use of the data for this analysis.

Several references discriminated between “retrofits” and “new”, “expansion”, or “replacement” systems. In most cases, only retrofit scenarios were appropriate for costing LOTs, since it typically should not be necessary to completely rebuild a system just to meet a certain LOT for the types of plants considered in this analysis. One exception to this could be lagoons, but as previously mentioned only one of the WWTPs evaluated was a lagoon (Whitefish) and it has plans to upgrade to activated sludge with BNR (an SBR).

All references discriminated between capital costs and recurring (i.e., O&M) costs and these costs were separately estimated for each plant evaluated. Estimated capital costs were converted to annual costs using standard engineering economics tables assuming an interest rate, i , of 5 percent and a term, n , of 20 years. Annualized capital costs were added to the annual O&M cost estimates to determine the overall annualized costs.

The references generally presented cost data as a function of plant capacity or treated effluent flows, typically by reporting costs in \$/MGD capacity (in some cases, \$/MG treated was reported for O&M costs). In many cases, to account for economies of scale, unit costs varied by the size of the plant (e.g., there might be separate \$/MGD values for WWTPs with flows < 1MGD, 1-10 MGD and >10 MGD). In these cases, the values for the appropriate size range was used.

In all cases, cost data were normalized to January 2016 costs by multiplying costs by the ratio of January 2016 cost index to the historical cost index for the study in question (RSMeans construction cost indexing data were used).

Where multiple references address similar LOTs (and similar existing facility “starting points”), we generally averaged the capital and O&M costs from the multiple references or options to determine a likely cost for achieving a certain LOT for final reporting purposes.

Cost estimates were based on facilities meeting the nutrient effluent limits at the point of discharge (end-of-pipe). For facilities with authorized mixing zones, costs may be lower.

Table 1. Key Major NPDES WWTP characteristics and associated preliminary cost estimation assumptions

Facility	Actual Average Daily Flow, AADF (MGD)	Actual Average TN (mg/l)	Permitted TN mass effluent limits/AADF (mg/l)	Actual Average TP (mg/l)	Permitted TP mass effluent limits/AADF (mg/l)	Facility Characterization and Assumptions
Bozeman	6.23	4.4	15.1	0.17	3.1	5-stage Bardenpho (biological N removal and EBPR). Effluent TP suggests that chemical P removal is also being used.
Butte Silver Bow	3.64	2.4	3.2	2.1	0.3	New MBR plant, so data is very limited. TP is reportedly around 0.2 now. Assume $LOT_{3.0TN}$ and $LOT_{0.5TP}$ currently.
Butte Highlands	Unk	Unk	0.08-0.27	Unk	0.008-0.02	Meets very low nutrient standards with membrane filtration.
Hamilton	0.68	3.13	16.6	3.38	18.6	Well under design flow, facility appears to be biological N removal or optimized accordingly. Secondary plant with simple modifications for TP removal.
Havre	1.38	7.92	NA	1.34	NA	A new BNR plant is under construction. Assume new facility will meet $LOT_{3.0TN}$ and $LOT_{0.5TP}$.
Helena	2.8	5.58	9.7	2.36	4.6	Biological nitrogen removal plant with no specific TP removal. Plant is reportedly already optimized and needs to do some small capital improvements.
Kalispell	2.7	8.4	17.6	0.15	7.1	Johannesburg process. biological N removal/EBPR. Not fully denitrifying. Excellent TP removal; mostly EBPR.
Lewistown	1.6	2.05	NA	0.49	0.7	Biological N removal/EBPR system. Meeting $LOT_{3.0TN}$.
Whitefish	0.92	24.2	22.9	0.47	1.0	Aerated lagoon with chemical TP removal. Plenty of capacity. Requires replacement to meet LOT for TN. An SBR is designed for construction in 2020 and it is assumed that it will meet $LOT_{7.0TN}$ and $LOT_{0.5TP}$.

¹ ADF = average daily flow; DF = design flow

Table 2. Key Minor NPDES WWTP characteristics and associated preliminary cost estimation assumptions

Facility	Actual Average Daily Flow, AADF (MGD)	Actual Average TN (mg/l)	Actual Average TP (mg/l)	Facility Characterization and Assumptions
Conrad	0.32	7	0.15	Extended aeration without chemical P precipitation. Optimized for $LOT_{7.0TN}$.
Chinook	0.11	2.9	1.84	Oxidation ditch, optimized $LOT_{3.0TN}$; no P removal.
Hinsdale	0.028	13	1.06	Extended aeration package plant. Incomplete nitrification/denitrification; no P removal.
Manhattan	0.15	8.7	0.6	Fixed film system with nitrification/denitrification; unknown P removal.
Colstrip	0.195	unk	unk	Oxidation ditch, unknown performance.
East Helena	0.307	10.6	0.53	Activated sludge plant. Pretty good nitrification, little denitrification. Good P removal.
Stevensville	0.344	14.8	2.835	Oxidation ditch, with nitrification but limited nutrient removal. Planning for a BNR upgrade.

¹ ADF = average daily flow; DF = design flow

Table 3. Upgrade options considered for Major NPDES WWTPs

Facility	Design Flow (MGD)	Actual Average Daily Flow (MGD)	Actual Average TN (mg/l)	TN per RPAWQBEL (mg/l)	Actual Average TP (mg/l)	TP per RPAWQBEL (mg/l)	LOT _{7,0TN} upgrade	LOT _{3,0TN} upgrade	LOT _{0,5TP} upgrade	LOT _{0,1TP} upgrade	LOT _{0,05TP} upgrade
Bozeman	8.5	6.23	4.4	N/A	0.17	N/A	N/A, currently meeting LOT	Optimization to meet LOT	N/A, currently meeting LOT	Optimize chemical precipitation and solids removal	High dosage chemical precipitation and advanced solids removal
Butte Silver Bow	5.5	3.64	2.4	N/A	2.1	N/A	N/A, currently meeting LOT	N/A, currently meeting LOT	N/A, new plant currently meeting LOT	Optimize chemical precipitation and solids removal	High dosage chemical precipitation and advanced solids removal
Butte Highlands	Unk	Unk	Unk	N/A	Unk	N/A	N/A, currently meeting LOT	N/A, currently meeting LOT	N/A, currently meeting LOT	N/A, currently meeting LOT	N/A, currently meeting LOT
Hamilton	1.984	0.68	3.13	4.2	3.38	1.3	N/A, currently meeting LOT	N/A, currently meeting LOT and RPAWQBEL	One point alum; Fermenter retrofit	N/A, LOT is below RPAWQBEL	N/A, LOT is below RPAWQBEL
Havre	1.8	1.38	7.92	6.7	1.34	1.1	N/A, assume new BNR plant can meet LOT	N/A, assume new BNR plant can meet RPAWQBEL	One point alum; Fermenter retrofit	N/A, LOT is below RPAWQBEL	N/A, LOT is below RPAWQBEL
Helena	5.4	2.8	5.58	N/A	2.36	N/A	N/A, currently meeting LOT	Retrofit with denitrification filters or step feed to BNR system	One point alum; Fermenter retrofit	Chemical precipitation and tertiary filtration	High dosage chemical precipitation and advanced solids removal
Kalispell	5.4	2.7	8.4	N/A	0.15	N/A	Optimization to meet LOT	Retrofit with denitrification filters or step	N/A, currently meeting	Optimize chemical precipitation and	High dosage chemical precipitation

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Table 4. Upgrade options considered for Minor NPDES WWTPs

Facility	Design Flow (MGD)	Actual Average Daily Flow (MGD)	Actual Average TN (mg/l)	TN per RPAWQBEL (mg/l)	Actual Average TP (mg/l)	TP per RPAWQBEL (mg/l)	LOT _{7,DTN} upgrade	LOT _{3,DTN} upgrade	LOT _{0.5TP} upgrade	LOT _{0.1TP} upgrade	LOT _{0.05TP} upgrade
Conrad	0.5	0.32	7	N/A	0.15	N/A	N/A, currently meeting LOT	Retrofit with anoxic zone to convert to MLE	N/A, currently meeting LOT	Optimize chemical precipitation and solids removal	High dosage chemical precipitation and advanced solids removal
Chinook	0.502	0.11	2.9	3.45	1.84	0.16	N/A, currently meeting LOT	N/A, currently meeting LOT	Retrofit with EBPR	Chemical precipitation and tertiary filtration	High dosage chemical precipitation and advanced solids removal
Hinsdale	0.03	0.028	13	None needed	1.06	None needed	N/A, no RPAWQBELs needed	N/A, no RPAWQBELs needed	N/A, no RPAWQBELs needed	N/A, no RPAWQBELs needed	N/A, no RPAWQBELs needed
Manhattan	0.37	0.15	8.6	0.3	0.6	0.05	Optimization to meet LOT	Retrofit with denitrification filters	N/A, currently meeting LOT	Chemical precipitation and tertiary filtration	High dosage chemical precipitation and advanced solids removal
Colstrip	0.6	0.195	Unk	N/A	Unk	N/A	Optimization to meet LOT	Retrofit with anoxic zone to convert to MLE	Retrofit with EBPR	Chemical precipitation and tertiary filtration	High dosage chemical precipitation and advanced solids removal
East Helena	0.434	0.307	10.6	N/A	0.53	N/A	Optimization to meet LOT	Retrofit with denitrification filters	N/A, currently meeting LOT	Chemical precipitation and tertiary filtration	High dosage chemical precipitation and advanced solids removal
Stevensville	0.344	0.344	14.8	1.13	2.84	0.4	N/A, assume new BNR plant can meet LOT	Retrofit new plant with denitrification filters	N/A, assume new BNR plant can meet LOT	Chemical precipitation and tertiary filtration	N/A, LOT is below RPAWQBEL

3.0 RESULTS

The results of our preliminary cost estimation exercise are summarized in Table 5 (for major WWTPs) and Table 6 (for minor WWTPs). Note that some of the options presented in the tables are likely to reduce the effective capacity of their WWTPs. This presumably has a “cost” that has not been explicitly factored into the evaluation. Tables 7 (for major WWTPs) and 8 (for minor WWTPs) reflect the percent of median household income that is currently paid for existing wastewater treatment and potential increases based on optimization or upgrades to achieve specific levels of treatment. The alternatives costed for each LOT is provided in Tables 5 and 6.

Table 5. Results of preliminary cost estimation exercise for Major NPDES WWTPs (all costs in 2016 dollars)

Facility	Treatment Objective	Capital Cost	O&M Cost	Annualized Costs ¹	Alternative	References
Bozeman	LOT _{3.0TN}	\$14,900	\$1,400	\$2,600	Optimization	EPA (2015), Water Planet (2016)
Bozeman	LOT _{0.1TP}	--	\$10,700	\$10,700	Optimize with higher alum dosing	Keplinger (2003), Scuras (2016)
Bozeman	LOT _{0.05TP}	\$18,720,000	\$3,888,000	\$5,389,300	Alum + Tertiary Clarifier + Filter + UF	Jiang (2005)
Butte Silver Bow	LOT _{0.1TP}	--	\$9,500	\$9,500	Optimize with higher alum dosing	Keplinger (2003), Scuras (2016)
Butte Silver Bow	LOT _{0.05TP}	\$15,120,000	\$2,592,000	\$3,804,600	Alum + Tertiary Clarifier + Filter + UF	Jiang (2005)
Hamilton	LOT _{0.5TP}	\$920,800	\$60,100	\$133,900	Average (1-point alum, fermenter, filter)	EPA (2008)
Havre	LOT _{0.5TP}	\$860,200	\$54,700	\$123,700	Average (1-point alum, fermenter, filter)	EPA (2008)
Helena	LOT _{3.0TN}	\$5,875,200	\$495,700	\$966,900	Average (denitrification filter, step feed)	EPA (2008)
Helena	LOT _{0.5TP}	\$1,624,300	\$117,700	\$248,000	Average (1-point alum, fermenter, filter)	EPA (2008)
Helena	LOT _{0.1TP}	\$3,490,600	\$466,700	\$746,700	Alum + Filter (two methods averaged)	EPA (2008)
Helena	LOT _{0.05TP}	\$14,544,000	\$2,520,000	\$3,686,400	Alum + Tertiary Clarifier + Filter + UF	Jiang (2005)
Kalispell	LOT _{7.0TN}	\$35,100	\$2,800	\$2,800	Optimization	EPA (2015a), Water Planet (2016)
Kalispell	LOT _{3.0TN}	\$5,875,200	\$495,700	\$966,900	Average (denitrification filter, step feed)	EPA (2008)
Kalispell	LOT _{0.1TP}	--	\$4,600	\$4,600	Optimize with higher alum dosing	Keplinger (2003), Scuras (2016)
Kalispell	LOT _{0.05TP}	\$14,544,000	\$2,520,000	\$3,686,400	Alum + Tertiary Clarifier + Filter + UF	Jiang (2005)
Whitefish	LOT _{3.0TN}	\$2,626,600	\$225,000	\$435,600	Average (denitrification filter, step feed)	EPA (2008)
Whitefish	LOT _{0.1TP}	\$1,739,500	\$178,700	\$318,214	Alum + Filter (two methods averaged)	EPA (2008)
Whitefish	LOT _{0.05TP}	\$7,447,680	\$1,729,000	\$2,326,700	Alum + Tertiary Clarifier + Filter + UF	Jiang (2005)

¹ Annualized costs are based on a discount rate, *i*, of 5%, and term, *n*, of 20 years.

Table 6. Results of preliminary cost estimation exercise for Minor WWTPs (all costs in 2016 dollars)

Facility	Treatment Objective	Capital Cost	O&M Cost	Annualized Costs ¹	Alternative	References
Conrad	LOT _{3,0TN}	\$597,456	\$111,239	\$159,155	Anoxic zone addition	Foess 1998
Conrad	LOT _{0,1TP}	--	\$900	\$900	Optimize with higher alum dosing	Keplinger (2003), Scuras (2016)
Conrad	LOT _{0,05TP}	\$5,065,310	\$550,007	\$956,245	Alum + Tertiary Clarifier + Filter + UF	Jiang 2005, EPA 2015b
Chinook	LOT _{0,5TP}	\$1,707,779	\$157,725	\$294,689	EBPR	Washington 2011
Chinook	LOT _{0,1TP}	\$1,683,999	\$361,476	\$496,533	Chem P + Filtration	Jiang 2005
Chinook	LOT _{0,05TP}	\$5,083,709	\$552,013	\$959,726	Alum + Tertiary Clarifier + Filter + UF	Jiang 2005, EPA 2015b
Manhattan	LOT _{7,0TN}	\$9,100	--	\$700	Optimization	EPA (2015), Water Planet (2016)
Manhattan	LOT _{3,0TN}	\$889,701	\$110,112	\$181,466	Post-treatment denitrification filter	Foess 1998
Manhattan	LOT _{0,1TP}	\$1,374,554	\$278,988	\$389,227	Chem P + Filtration	Jiang 2005
Manhattan	LOT _{0,05TP}	\$3,856,995	\$418,101	\$727,432	Alum + Tertiary Clarifier + Filter + UF	Jiang 2005, EPA 2015b
Colstrip	LOT _{7,0TN}	\$14,800	--	\$1,200	Optimization	EPA (2015), Water Planet (2016)
Colstrip	LOT _{3,0TN}	\$709,506	\$129,239	\$186,141	Anoxic zone addition	Foess 1998
Colstrip	LOT _{0,5TP}	\$2,041,170	\$188,516	\$352,218	EBPR	Washington 2011
Colstrip	LOT _{0,1TP}	\$1,896,196	\$420,565	\$572,640	Chem P + Filtration	Jiang 2005
Colstrip	LOT _{0,05TP}	\$5,979,542	\$649,556	\$1,129,116	Alum + Tertiary Clarifier + Filter + UF	Jiang 2005, EPA 2015b
East Helena	LOT _{7,0TN}	\$10,700	--	\$900	Optimization	EPA (2015), Water Planet (2016)
East Helena	LOT _{3,0N}	\$1,009,000	\$123,700	\$204,600	Post-treatment denitrification filter	Foess 1998
East Helena	LOT _{0,1TP}	\$3,220,910	\$183,380	\$441,697	Alum addition and filters	Washington 2011
East Helena	LOT _{0,05TP}	\$4,455,106	\$483,442	\$840,741	Alum + Tertiary Clarifier + Filter + UF	Jiang 2005, EPA 2015b
Stevensville	LOT _{3,0TN}	\$841,000	\$104,600	\$172,000	Post-denite filter	Foess 1998
Stevensville	LOT _{0,1TP}	\$1,309,493	\$262,253	\$367,274	Chem P + Filtration	Jiang 2005

¹ Annualized costs are based on a discount rate, *i*, of 5%, and term, *n*, of 20 years.

Table 7. Percent of Median Household Income Relative to Treatment Levels for Major NPDES WWTPs

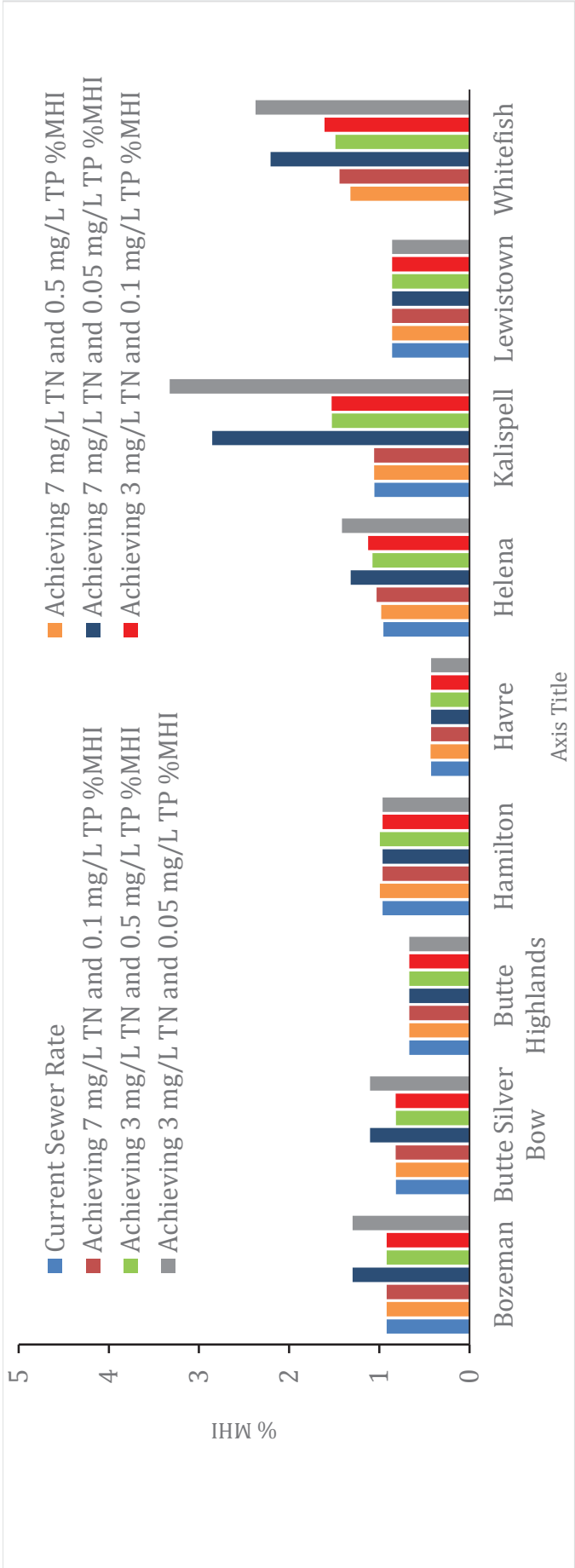
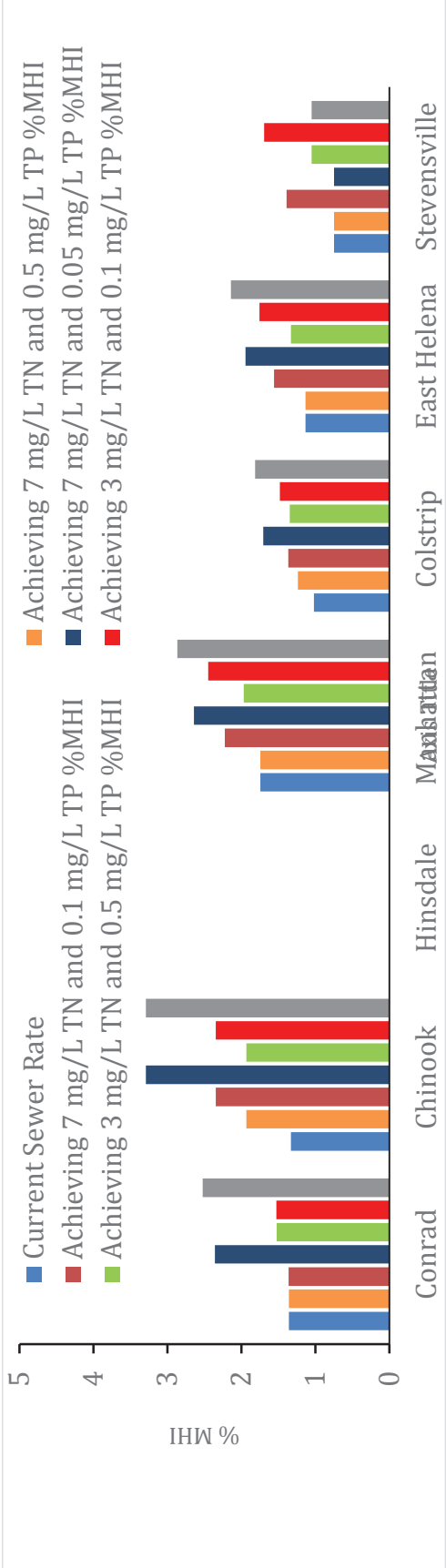


Table 7. Percent of Median Household Income Relative to Treatment Levels for Major NPDES WWTPs



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